MONTHLY WEATHER REVIEW

Editor, EDGAR W. WOOLARD

VOL. 68, No. 3
W. B. No. 1290

MARCH 1940

CLOSED MAY 3, 1940
ISSUED JUNE 24, 1940

ON THE DISTORTION OF STREAM FIELDS BY SMALL HEAT SOURCES

By J. J. GEORGE

[Eastern Air Lines, Hapeville, Ga., May 1939]

The effect of comparatively small heat sources on cold currents has attracted little attention. Most writers confine themselves to mentioning that such heat sources produce instability and perhaps squalls in the area which lies in the "shadow" of the heat source. Such a problem is of considerable importance in forecasting, and several complications not generally recognized are introduced.

The problem was called to the writer's attention by H. T. Harrison [1] in a paper investigating terminal conditions at Chicago and Cleveland airports. Each of these airports is adjacent to the Great Lakes, and these lakes at certain times of the year and with appropriate conditions serve as heat sources such as we have under consideration. Harrison mentioned in his paper a frontal effect observed at both stations which did not seem to move with the gradient wind, but rather appeared almost stationary. The front produced moderate snow and was characterized by a change in wind direction as well as in temperature and humidity.

In an effort to arrive at a logical explanation of the observed phenomena, it will be necessary first to make certain simplifying assumptions and later apply empirical corrections. Elliott [2] has shown how discontinuities are formed over the heat source of the Florida Peninsula. Although not entirely dissimilar, there are significant differences in the two problems. In Florida, motion begins from a condition approximating rest and proceeds freely to an equilibrium of sorts. In the problem considered here, cold air initially in motion passes over the heat source, and equilibrium is not reached—at least, not over the heat source.

Referring to figure 1a, the heat source is designated by the heavy solid lines forming a square. It is assumed that the heat source is a lake of comparatively warm water 200 miles on each side. A cold (with reference to the lake water) horizontally homogeneous current is flowing toward the lake with a gradient velocity U_o.

It should be remarked here, that the instability produced by the lake is directly dependent on U_o, since, if a certain critical value is reached which depends upon initial temperature conditions, it is obvious that the air could pass over the lake without allowing time for sufficient heating to produce the characteristic squalls, and further that the degree of heating is a function of the time spent in crossing the lake. U_o is taken as 30 m. p. h. for purposes of computation in this paper. Dry adiabatic lapse rates are assumed throughout the layers concerned. This assumption does not differ greatly from actual conditions, since Rossby and Montgomery [3] have shown that a lapse rate approximating the dry adiabatic will be established up to about 1 km. in a current of this magnitude with the character of terrain assumed to surround most lakes. The action of the warm source will be to lift the inversion at the top of the turbulent layer from about 1 km. above the surface to about 2½ km. This last value is deduced from reports of the top of the instability cloud decks in the lee of the Great Lakes.

This means that the layer originally 1 km. thick has been increased 2½ times during the passage of 200 miles. It is important to know if the original turbulence inversion was strong enough to limit convection and hence if the additional air was supplied from the sides of the lake. If the heating across the lake is 15° F., the turbulence inversion must be about the same if it is to limit the convection. A more nearly normal value of the turbulence inversion would be 4° F. Further, a short calculation is sufficient to show that the order of magnitude of the wind from each shore toward the lake would have to be about an average of 20 m. p. h., assuming the inflow to occur through the lower 500 meters. No velocities at all comparable to this are observed in practical cases, so it must be concluded that convection takes in more and more air into the lower layer from above. Since this layer becomes thicker as it advances over the lake, there is more air to heat as it progresses, and, in addition, the air more nearly approaches the lake surface temperature. For these reasons the isotherms shown as dashed lines in figure 1, show the most rapid rise in temperature of the layer to be near the windward shore. Ideally, a mathematical temperature discontinuity would be formed at the lake sides (AB and DC in fig. 1a), but horizontal lateral mixing modifies it somewhat and the isotherms have indicated a close approach to the actual condition with a zone of transition.

The short, heavy arrows represent the surface wind. It is assumed that the angle between the surface wind and the gradient wind is 25° over the land surface and that this angle decreases to 18° over the lake. These figures are obtained from the work of Rossby and Montgomery,[4] and correspond respectively to an average obstruction of about 16 meters over land and 30 cm. over water. It is further considered that due to this same effect of decrease of surface friction, that the winds in the surface layers over the lake must be increased something on the order of 20 percent. In this way, any area of suddenly increased or decreased surface friction acts as a refraction device to surface winds. Further, an increase of friction has the effect of piling up air along the boundary of the increase. If stable air is considered, the refraction will be intensified although the absolute velocities will be lowered.

In addition to this effect, Brunt [5] has pointed out that in a condition of this kind, the warmed air would be subjected to an increase in velocity proportional to the decrease in density. If we assume the total heating of the layer to

[1] H. T. Harrison, *Terminal Weather Conditions on the Newark-Chicago Airway.* United Air Lines Publication.

[2] R. D. Elliott, Land and Sea Breezes in Florida, (Not published.)

[3] C. G. Rossby and R. B. Montgomery, The Layer of Frictional Influence in Wind and Ocean Currents. vol. III, 3, Papers in Phys. Ocean. M. I. T. and Woods Hole Ocean. Inst.

[4] Loc. cit. fig. 3.

[5] D. Brunt, Physical and Dynamical Meteorology, 1st ed., p. 177.

be 15° F., between shores, then this factor will amount to an increase in velocity not only of surface, but of gradient wind of the order of 3 percent. These increases in velocity cause an increase in the Coriolis Force, which tends to deflect the current farther to the right over the lake. Left and right are used throughout with the observer facing downwind. It will presently be seen that this deviation is of little significance above, say, 1 km., but for the surface layers it is of definite importance. In this way, decreased surface friction produces immediate convergence along the right hand bank at very low levels.

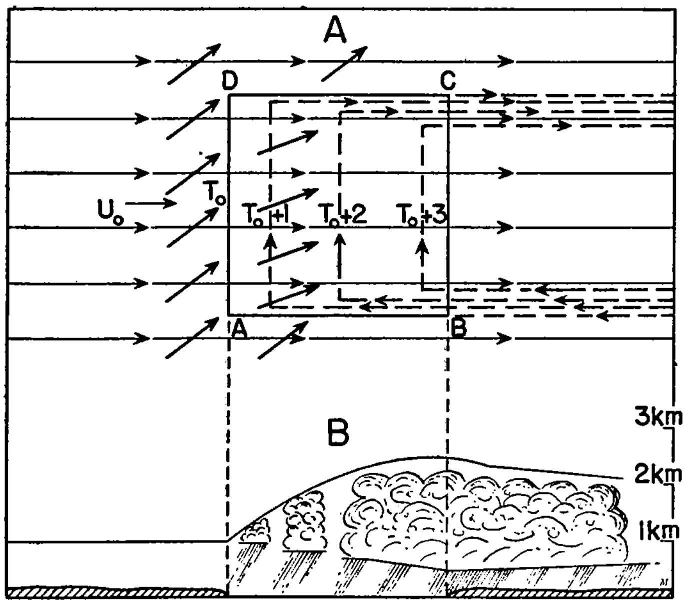

Figure 1.

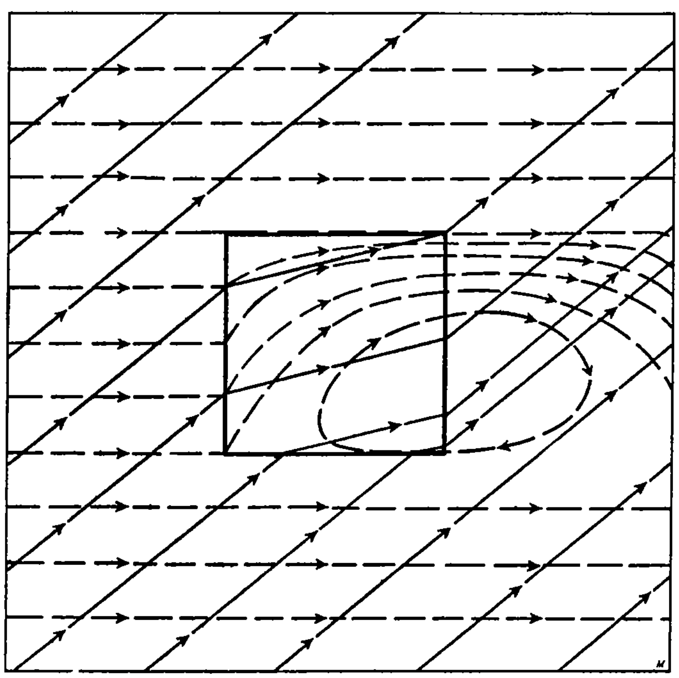
Figure 2.

Figure 1b shows a longitudinal section along the center line of the lake. Notice that the most rapid rise in the dome occurs near the windward shore and that the maximum height occurs over the lee shore, since the heating process is cumulative.

It has been shown that the wind aloft at any level z, is closely approximated by the vector addition of the gradient wind and the thermal wind. This latter component is considered to blow around low temperature in the same sense that the barometric wind does around low pressure, i. e., always tangential to the mean isotherms

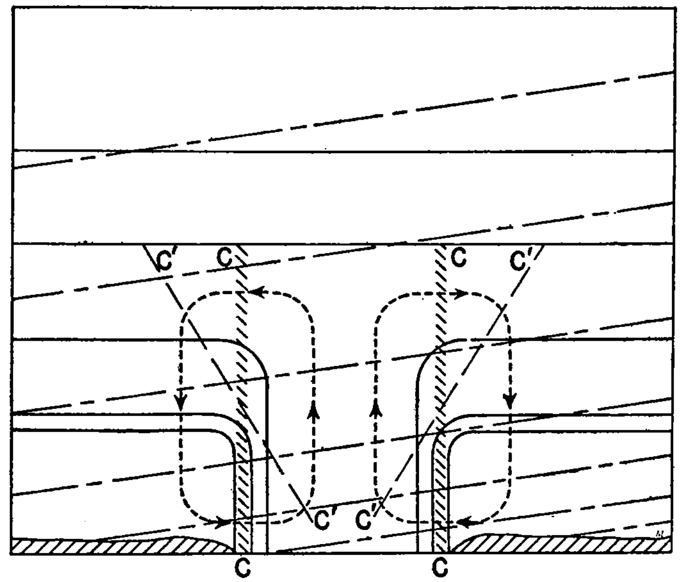

Figure 3.

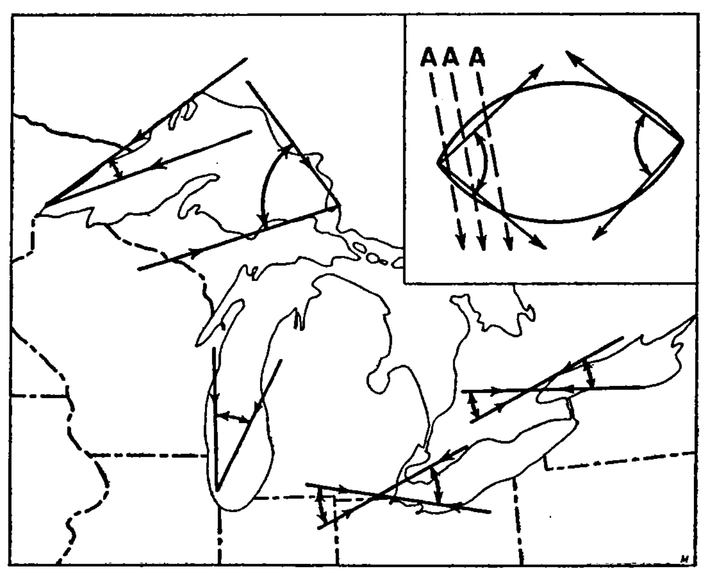

Figure 4.

and of a magnitude proportional to the temperature gradient and to z. Heating of 15° F. across the lake produces a thermal component on the order of 50 m. p. h. directed to the left. Along the lake sides, the thermal component increases with the creation of new isotherms reaching a maximum at the lee shore. This component is several times the magnitude of the gradient flow, and if no other factor were operating, would produce an actual reversal of flow along the right shore at higher levels and an enormous increase in the flow on the left shore.

Figure 2 shows the stream lines formed under the conditions postulated above, but with frictional drag being considered only in the lower layers. The solid lines are the stream lines of surface flow, and the dashed lines represent the flow near the top of the convective layer. Note that an anti-cyclonic eddy has been established in the upper level, and that results so far, point to a marked speeding up of air flow in the left side of the lake aloft and a reversal of flow on the right side. The refraction effect in the surface layers shows clearly in the surface stream lines. It should be noted here for later reference, that greatly increased values of the surface wind should be found on the right hand portion of the lee shores of lakes with subnormal velocities above.

Figure 3 shows a cross section transverse to the main current after a part of the lake has been traversed. The solid lines are lines of equal potential temperature which may be substituted for isosteres. The effects of condensation have been neglected. A concentration of the isentropic surfaces such as we see here is characteristic of a surface of discontinuity. In this case the surface separates the warm air over the lake from the air which has had no history over the water. Since the vertical extent is undoubtedly confined to the lowest three km. and the horizontal extent of the warmed air is comparatively slight, it is preferred to use the term, "Pseudo-front," which Shinze has applied to discontinuities of this nature.

The tubes or solenoids formed between the isobaric surfaces which are represented by broken lines, and the isentropic surfaces, form a measure of the acceleration of circulation transverse to the main current. It is not difficult to evaluate this force numerically, but other factors reduce its effect to such an extent that it does not appear that such calculation would be of material assistance. However, the circulation tendency, which of course, acts in such a way as to bring the isentropic surfaces into coincidence with the isobaric surfaces, is such as to cause the pseudo-fronts to rotate toward the lake at the bottom and away at the top. This means that the psuedo-fronts which are formed nearly perpendicular (at c) assume more and more slope as the lake is traversed. It must be observed that as these fronts move farther out into the lake (as at c^1–c^1), convection and heating in the cold air tend to destroy them—at least in the lower portion, and it seems probable that this does occur. Certainly, this effect would be greatest at the lee shore, where the front should theoretically extend farthest into the lake. These fronts will have no tendency, under ordinary conditions to become migratory since they are formed, and remain, parallel to the principal flow. This agrees with Harrison's observations. Rising air is indicated for the center of the lake, and an outflow at the top of the warmed air. This would mean a tendency for an anticyclonic eddy in the expanded portion at the top of the current and a cyclonic eddy at the lake surface, which gives us a separate, but similar picture to that obtained previously. This is nothing more than the process for the formation of a shallow thermal cyclone. Indeed, the character of distortion produced, varies between the extremes of an actual formation of a small thermal cyclone for conditions in which U_o approaches O, to merely the steepening of lapse rates with perhaps incidental squalls for the condition when U_o becomes so great that it allows insufficient time for heating as the lake is crossed.

The idealized results obtained above will be profoundly modified by three factors. First, the fact that equilibrium flow is not attained implies that only the tendency for certain of the effects considered is present. Second, the warmed air is highly unstable and active convection is taking place throughout its extent. Third, the action takes place in a sort of tunnel, totally enclosed on the sides by the psuedo fronts and on the top by the convective inversion. Under these conditions, and since the extent of the heated air is not great either horizontally or vertically, frictional drag from the air masses on either side and top of the tunnel will be very appreciable. These forces all exert a marked damping effect on all of the influences considered except surface friction.

The practical end condition which seems probable resembles in some respects the stationary whirl in a moving fluid caused by an obstruction. It is certainly not expected that a complete anticyclonic eddy will result in any cases where the gradient flow is considerable, but it is expected that a tendency to establish such a circulation should be evident even in strong flow and that the idealized circulation be closely approached for weak gradient flow.

The obvious source for data to prove such a circulation is the Great Lakes. Unfortunately, the condition is always characterized with low clouds, squalls, and precipitation, which prevent balloon soundings just when they are needed. Radiosondes would have to be more closely placed than practicable to be of much use.

Despite these objections, one case has been found that seems to illustrate some of the points considered. On March 7, 1939, a cold fairly uniform current of Pc air was flowing over the lakes from the northwest. The balloon runs from Chicago and Sault Ste. Marie, both for 0500,

Table 1

Altitude	Chicago	Sault Ste. Marie
Surface	330–20	[1] 320–20
1,000	330–20	330–22
2,000	330–24	340–36
3,000	320–24	340–46
4,000	310–28	330–42
5,000	300–42	320–38
6,000	300–46	310–40
7,000	300–54	310–44
8,000	300–52	

[1] Directions: W=270°, N=360°. Velocities in m. p. h.

are reproduced in table 1. The corresponding temperature soundings show adiabatic lapse rates up to 4,000 and 8,000 feet respectively. It seems fair to choose as the gradient wind for Chicago the value 24 m. p. h., and for Sault Ste. Marie, 46 m. p. h. We are interested particularly in the ratio of surface to gradient wind. For average land cases it should be about 0.5 or 0.6 for winds of these velocities, yet the ration at Chicago is 0.83 and at Sault Ste. Marie, 0.43. In the former case the ratio is much too high, indicating either too much surface wind or too little wind aloft, and the reverse at Sault Ste. Marie. While these stations are not very satisfactorily located for this purpose, nevertheless the values agree with expected results.

In a further effort to obtain supporting synoptic evidence, data from New Orleans' Shushan Airport were examined. This airport lies just east of the center on the south shore of Lake Pontchartrain. This lake is 25 miles in north-south extent by about 40 miles east-west. These dimensions are too small to expect much circulation aloft, but the surface winds should indicate such a pattern as shown in figure 2 for almost any size body of water.

TABLE 2

	West	Northwest	North	Northeast	East
Number of observations	8	16	33	21	21
V_{no} (modified Beaufort)	2.1	4.4	4.3	2.9	2.8
V_m (modified Beaufort)	2.2	2.4	2.1	1.9	2.1
$\frac{V_{no}}{V_m}$	.94	1.80	2.08	1.53	1.29

V_{no}=Anemometer velocity at New Orleans airport (66.1 feet above surface).
V_m=Anemometer velocity averaged for three surrounding stations. (Mobile, Tyler, Lake Charles).

The data in table 2 are taken from winter synoptic charts without regard to time but when no fronts were within a hundred miles. Diurnal effects should be practically eliminated between day and night readings. It must be remembered that the normal value for the ratio, V_{no}/V_m should be approximately 1.4 for wind directions between WNW. and E., through N., since the lower frictional drag of the water surface at New Orleans would increase the surface wind about this much above the land exposures of the surrounding stations. The west winds which are not affected by the lake, show nearly the expected value of 1.0. The NW. and N. winds, as expected, show values much greater than normal, while the NE. and E. winds show marked decreases to near or below normal. East winds should show a marked deficiency in this value, and that they do not, is attributed to the fairly uniform, low value of surface friction to the east of the airport composed of low grass marshes and water surfaces. The average wind at New Orleans from N. and NW. is found to be 4.4 modified Beaufort, or approximately 18 m. p. h. while these same directions give averages in the surrounding stations of 2.2 or about 8 m. p. h.

Table 3 is offered to show that air drainage, while perhaps a definite factor, is not the controlling force. Three New Orleans balloon runs are given for 1,100, 1,700, and 2,300, seventy-fifth meridian time April 7, 1939. They are typical of such balloon runs from north through northwest. In two of them, the ratio of V_a/V_1 is above 1.0, which is a very unusual occurrence, yet one that is probable according to figure 2. At no time does this value drop to a normal figure. The lowest ratio of 0.92 occurs at 1,100, but the wind direction of 10° to 20° which is slightly unfavorable for this effect, probably accounts for even this low a value.

TABLE 3

Altitude	1,100 ES	1,700 ES	2,300 ES	Estimated normal over sea surface for adiabatic lapse rates
Surface	360–22	360–20	350–19	
1,000	10–24	340–17	340–10	
2,000	10–20	360–16	340–10	
3,000	20–19	10–17	350–11	
V_a/V_1	0.92	1.2	1.9	0.8

V_a=anemometer wind. V_1=wind at 1,000 feet.

Some attention should be paid to the conditions of formation of the pseudo fronts mentioned before. Figure 4 shows the directions of wind which permit the formation of these fronts for each of the Great Lakes. The insert at the upper right shows how these directions were obtained. Since the lakes are not squares, it is necessary to choose the directions in such a manner that the wind blows along the edge and not across the corner of lakes. For instance, if the direction were taken as along the dotted lines marked "A" in the insert, air progressively crosses more water toward the center and a gradual zone of transition is produced instead of a discontinuity.

SUMMARY

(1) It is found that there is definite increase in surface wind velocities on the right portion of the lee shore of lakes (looking down-wind).

(2) It is probable that a marked increase in velocity at the top of the convective layer is found to the left of large warm lakes, and a decrease to the right.

(3) That the effects in (1) and (2) above vary from the formation of pure thermal cyclones, for wind velocities approaching zero, to merely a steepening of lapse rates for very high wind velocities, and a smaller lake traverse.

(4) That stationary, pseudo fronts will be formed only under certain local conditions.

THE RELATION OF WEATHER FACTORS TO WHEAT YIELDS ON LEVAN RIDGE, UTAH [1]

By NORAH E. ZINK

[Geographer, State Teachers College, Indiana, Pa., February 1940]

Much interest exists in the relation of weather to crop yields. Some of this interest is occasioned by the desire to forecast yields and thus to predict, at least in part, economic conditions at the time of harvest, or to change farm practices in order to avert loss. Some of the interest is manifested because of the desire to determine the suitability of a region to a specific method of development; the geographer uses the correlation of weather data and crop yields as a means of delimiting regions or interpreting man's activities in relation to his natural environment.

WEATHER FACTOR IMPORTANT TO WHEAT GROWTH AND YIELDS

Opinions of students of the relation of yields to weather data suggest that a large number of factors are important over wide areas. Some of these factors are the amount, distribution, reliability and effectiveness of rainfall; evaporation; maximum, minimum, and average temperatures; length of drought periods; length of growing season; and amount of sunlight and soil moisture.

Some investigators use the month or the year as a unit of time. Others are concerned with stages of plant growth; many plants have a particular period during their growth when certain weather factors or combinations of factors are thought or known to be necessary to produce large yields, and since the presence or absence of these factors at a so-called critical stage is perhaps more important than favorable weather conditions throughout the rest of the plant's life, the use of plant-growth stages as time-factors is superior to monthly or yearly divisions. There are, however, two difficulties in the use of plant-growth stages. In the first place, there are almost no records giving dates for these stages. Secondly, the dates differ from year to year, and from one place to another. Among those advocating the use of plant-growth stages in making correlations between yields and weather factors are J. Warren Smith in this country, and Girolamo Azzi in Italy.[2]

[1] The advice and assistance of Dr. John Kerr Rose in the preparation of portions of this study is gratefully acknowledged.

[2] Azzi, Girolamo, "Problems of Agricultural Ecology." MONTHLY WEATHER REVIEW, April 1922, 50: 193.